Data Assimilation and Ocean Data Quality Control Upgrades in SWAFS

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LONG-TERM GOALS

The goal of this project is to improve the forecast performance of shallow-water and limited-area ocean forecast systems through improvement in ocean data analysis and assimilation techniques.

OBJECTIVES

The Shallow Water Analysis and Forecast System (SWAFS) is the operational ocean nowcast/forecast system at the Naval Oceanographic Office (NAVOCEANO). The objective of this project is to improve the forecast skill of SWAFS by integrating into the NAVOCEANO system some of the technology planned for transition to the Fleet Numerical Meteorology and Oceanography Center (FNMOC) for use with the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS). The ocean data quality control, analysis, and assimilation components of SWAFS will be upgraded.

APPROACH

SWAFS is an operational nowcast/forecast system used at NAVOCEANO for predicting the three-dimensional current and thermohaline structure of the ocean. Presently, SWAFS produces forecasts for sixteen areas including the Persian Gulf, Arabian Sea, Mediterranean Sea, and Baltic. Larger areas such as the northern hemisphere, the Western Pacific, and the northern Indian Ocean are run to provide outer boundary conditions for the higher resolution nests in the marginal seas.

The modeling system uses a 3D primitive equation numerical circulation model as its dynamical core. The model is an upgraded version of the Princeton Ocean Model that has been converted to MPI code, has updated code for correction of the error from the pressure gradient truncation, and includes Lagrangian trajectory simulation companion codes. SWAFS routinely applies tidal forcing, in addition to using Navy forecasts of surface winds, air temperature, and vapor pressure to calculate air-sea momentum and thermal fluxes. SWAFS produces two separate two-dimensional optimal interpolation analyses daily. The first analysis, using satellite retrievals of sea surface temperature (SST), constrains the model surface temperatures. The second analysis, using *in situ* temperature and salinity profiles, is applied at depth. Synthetic profiles from the global MODAS analysis can also be included in the

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second analysis step. The analyzed fields are then individually relaxed into the model with prescribed relaxation time scales.

The ocean data assimilation package developed for COAMPS improves on the univariate optimum interpolation (OI) approach with a fully multivariate, three-dimensional OI ocean data analysis capability (3DMVOI). The 3DMVOI and accompanying data quality control software use all operationally available data types to produce 3D analyses of temperature, salinity, geopotential, and u-v velocity components. MODAS synthetic profiles can also be included in the 3DMVOI analysis. The synthetic profiles are generated in areas where the measured changes in sea surface height anomaly (SSHA) are considered significant. The 3DMVOI analysis code can be cycled on itself, when it uses a previous analysis for the background, or it can be cycled with a dynamical model and use a model forecast as the first guess field.

The 3DMVOI has several distinct advantages to the more traditional univariate 2D OI analysis systems such as OTIS, MODAS, and the system presently in SWAFS. The fully three-dimensional analysis permits direct assimilation of single level point or threaded data, such as observations from AUVs or SSTs, which cannot be easily interpolated to the analysis depths. In addition, the multivariate method allows adjustments to the ocean mass field to be correlated with adjustments to the ocean current field, thereby providing balanced initial conditions for the ocean forecast model. For comparison with the univariate 2D OI analyses of temperature and salinity in SWAFS, the 3DMVOI can be used to simulate a 2D analysis by defining the vertical correlation length scales to be negligible. As the analysis capability is extended to assimilate multiple variable types from a number of different sources, new quality control (QC) techniques must be developed for those observations. An ocean data QC system has been developed as an integral part of the 3DMVOI. The QC system can be customized for the SWAFS data flow with a look forward to new data streams that are coming on line (ARGO, microwave SSTs, etc).

The expected improvements from the 3DMVOI upgrade to the SWAFS data assimilation component are the following:

1) allows the use of in situ surface observations (ships, fixed and drifting buoys) in the SWAFS SST analysis;
2) provides full-depth temperature and salinity analyses performed in 3D with velocity increments consistent with the mass field updates;
3) improves the diagnostic information on the performance of the analysis and of the forecast model;
4) permits users to adjust the performance of the analysis with simple changes via namelist variables;
5) improves the quality control of the ocean observations.

To achieve these improvements, the following technical approach is being implemented.

Implement the development copy of SWAFS and synchronize configuration management: A copy of the present operation SWAFS has been implemented for development. The initial beta system is a copy of the operational Northwest Pacific SWAFS nest, and runs on the same NAVOCEANO MSRC platform using observational data, boundary condition, and forcing fields archived from the operational run. The next implementation will access the operational data streams directly, and the final development system will be a port of the existing nest to the new MPI code on a scalable multiprocessor system at the MSRC.

Develop diagnostic and validation tools: Tools for validating the skill of the SWAFS model and for evaluating the quality of the analysis are being developed with a goal towards establishing the accuracy of the forecasts issued from the analysis. Measures of forecast skill include case-by-case and statistical comparisons with observations not yet assimilated, bulk statistics that measure improvements over persistence for the data used in the analysis (e.g., RMS error, correlation), and subjective evaluations of whether the forecasts are physically reasonable. The forecast skill estimates will also include data types not used in the analysis, for example SEASOAR and ADCP data, plus other special data collected by NAVOCEANO.

Evaluate the operational system: A key ingredient to the success of a 3DMVOI analysis is proper specification of the various statistical input parameters that are required a priori by the technique. It is expected that the prior statistical parameters will be both region and time dependent, and perhaps depth dependent. The horizontal and vertical correlation length scales from a time history of the innovations (observation-minus-forecast) will be calculated using the innovation correlation method (Daley, 1991). This method also provides initial estimates of observation and forecast error variances. The consistency of the estimates will be check using the spatial structure of the residuals (observation-minus-analysis). In principle the analysis residuals should be spatially uncorrelated. Any spatial correlation remaining in the residuals represents information that has not been extracted by the analysis (Hollingsworth and Lonnberg, 1989). In addition, the chi-squared statistic is calculated; this measures the consistency of the innovations with the specified observation and background errors (Bryson and Ho, 1975; Bennett 1992). When the innovations in a particular region or for a given observing system are very different from what has been assumed, then it is possible to detect biased observing systems or mis-specification of the error variances. The technique avoids the use of ad hoc methods in the evaluation of the priors used in the 3DMVOI.

Install the QC system: The ocean data QC routines that have been developed as an integral part of the 3DMVOI are being installed, and adapted to read the existing SWAFS data stream. The 3DMVOI QC uses static (GDEM) and dynamic (MODAS) climatologies as well as previous analysis or forecast fields to determine the validity of the data. The QC system updates the observation data files that are in turn read by the 3DMVOI software.

Install and evaluate upgrades to the OI system: The 3DMVOI code will be implemented in SWAFS and changes in model performance and forecast skill will be documented. Tuning of the 3DMVOI statistical input parameters and error correlation models will be based on estimates of a priori statistics obtained from the operational SWAFS. The first set of comparisons of the analysis cycling with SWAFS will be performed using these results. The next tests will install the analysis code as part of the forecast update cycle in SWAFS, using the existing relaxation technique. The present technique pushes the mass fields toward the analysis value, and allows the velocity fields to adjust as to any other forcing term. The relaxation time scale is an adjustable parameter, and in SWAFS it is a function of the expected error of the analysis, and the depth. This set of comparisons between the operational model and the upgraded model will highlight the effect of the 3DMVOI on the nowcast and forecast results.

Optimize the data assimilation method: An incremental updating technique will be implemented; the model mass and velocity fields will be adjusted once at the beginning of the forecast with the new analysis output. Two groups at NRL Monterey are testing this approach, using 3DMVOI with NCOM (regional, COAMPS) and with POP (global, NOGAPS), and their experience will be helpful as we determine the appropriate approach for SWAFS. The degree to which model characteristics determine the success of the incremental updating technique is not known; consequently the 3DMVOI in SWAFS will be evaluated with the relaxation method.

WORK COMPLETED

An initial meeting of the investigators with the NAVOCEANO SWAFS team was held, where the northwest Pacific SWAFS nest (pacnest) was chosen for the first parallel-ops development version of the upgraded system. The pacnest parallel ops run has been installed, and runs on the same NAVOCEANO MSRC platform using observational data, boundary condition, and forcing fields archived from the operational run. An archive of the operational output was installed, and has now stored up to several months' of operational output for five of the operational SWAFS domains. In addition, daily restart files are being archived for the development pacnest domain (in addition to the operational archive or weekly files). This effort has already identified problems with model input files, for the North Arabian Sea domain, and with the interpolation of NOGAPS forcing fields to the ocean model grid.

The analysis and data QC codes were updated to include GOES SST data, which required that the codes now track data cuts to the nearest minute due to the volume of data (GOES 8 and 10 data counts amount to about 5 to 6 million obs each day). The QC code was also modified to flag, rather than edit, profile data. Multiple flags can now be appended to the data to indicate which QC tests the profile failed.

RESULTS

Using the archived output, it is possible now to begin exploring the system performance with subjective measures (e.g., examining graphical display of the model output for obvious artifacts, Figure 1) and objective measures (i.e., bias and root mean square error referenced to observations, Figure 2) of performance. A subset of the daily operational SWAFS output is displayed graphically on a web page made available to the SWAFS team at NAVOCEANO, and used for monitoring the system performance. Nowcast/forecast statistics at taus out to 48 h are also calculated weekly and made available to the SWAFS team.

IMPACT/APPLICATIONS

The results of this effort will affect most directly the operational SWAFS system, but advances in the data analysis 3D MVOI methodology and the data assimilation techniques will apply to other nowcast forecast systems under development, and the analysis and forecast diagnostics can or will be applied to other systems.

TRANSITIONS

Under SPAWAR co-sponsorship of this project, the upgraded SWAFS system will be transitioned for use at NAVOCEANO, where it will continue to be the operational regional and limited-area ocean nowcast/forecast system. The transition products include the ocean data QC code, the upgraded SWAFS code with the 3DMVOI, diagnostic software, and documentation. The ocean data quality control software will have broader application to other analysis and forecast systems at NAVOCEANO. The diagnostic software will be used in monitoring other operational analysis and forecast systems and NAVOCEANO. The results from optimizing the data assimilation method will be of interest to the global and regional NCOM developers.

RELATED PROJECTS

This work is related to the ocean analysis development for COAMPS (ONR 6.2 and SPAWAR 6.4), MODAS Improvements (ONR 6.2), and global NCOM development (SPAWAR 6.4) efforts.

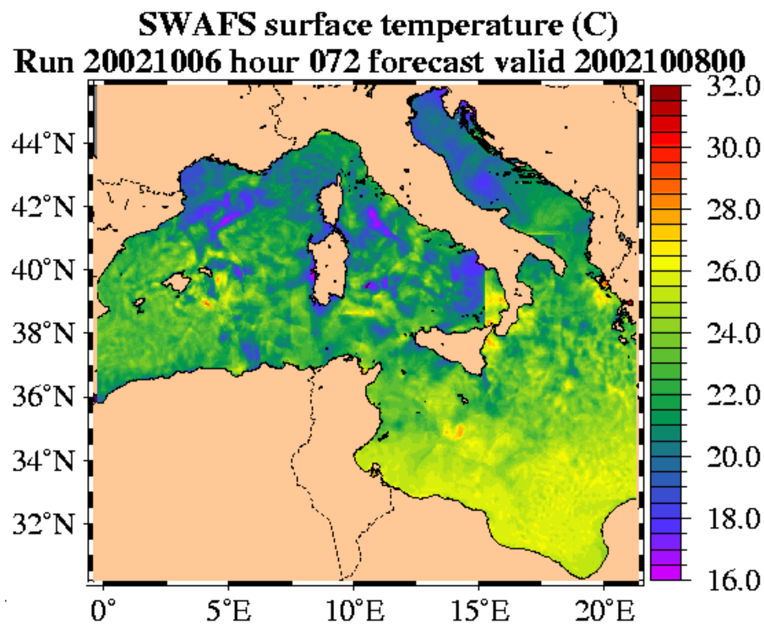

Figure 1. Surface temperature (SST) from the 48 h forecast of the 20021006 run of the SWAFS Mediterranean domain. Only a subset of the domain is shown. Note the artificial features along 15.2 E and 41.3 N.

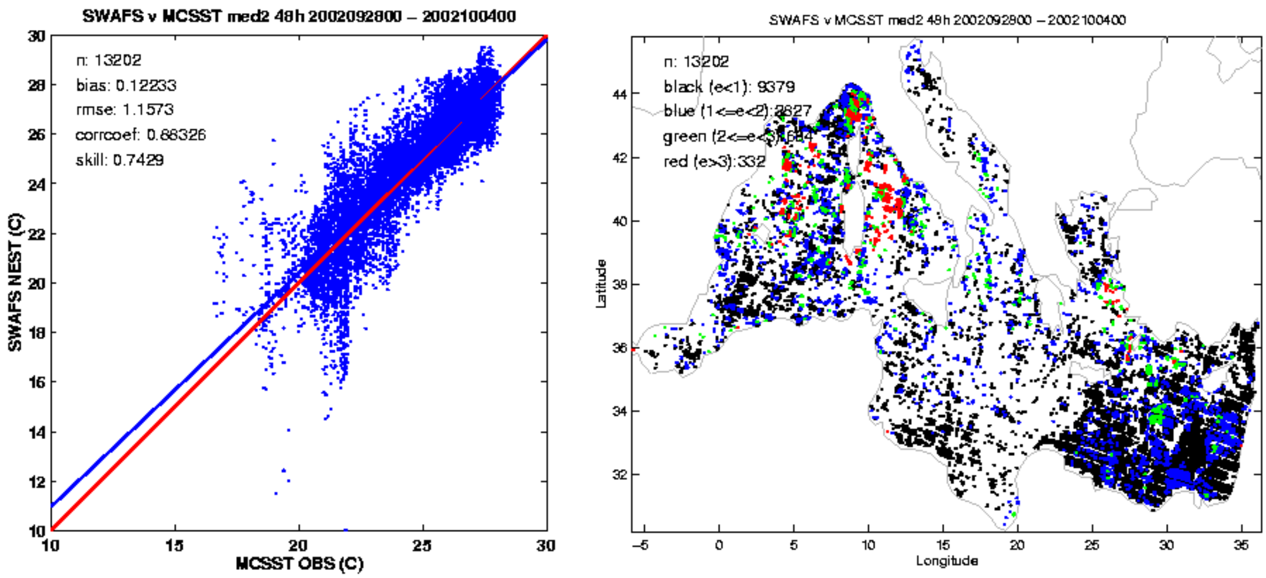

Figure 2. SWAFS Mediterranean domain surface temperature 48 h forecast skill measured against satellite observations for the period 28 Sep 2002 to 04 Oct 2002. Left panel, a scatterplot of model v. observation values. The blue line represents the best fit; perfect matches would lie along the red line. Right panel, the geographical distribution of the observations, with the observations colored by the model forecast error as noted in the figure, so that observation locations with large forecast errors are readily apparent.

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